

Design Thinking as a Framework for Teaching Packaging Innovation

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ABSTRACT

Students in scientific/technical-oriented disciplines struggle with achieving good levels of innovation when exposed to design problems. Research indicates the need for implementing alternative pedagogical approaches in technical curricula that enhance students' creative skills. The purpose of this study was to evaluate the implementation of a cross-disciplinary pedagogical approach with a focus on teaching innovation in the field of packaging engineering at a university in the United States. A Design Thinking Project-Based Learning (DTPBL) approach was used to improve the levels of innovation in student work. Its outcomes were compared with those of a Traditional Project-Based Learning (TPBL) approach. The implementation of DTPBL across several courses took place between 2015 and 2018. TPBL was the norm in these courses between 2009 and 2014. National and international student design competitions were used to assess the level of innovation of student work externally. Statistically significant differences were found in the levels of innovation of student work between approaches. DTPBL projects placed higher in design competitions, and they were recognized more often by independent expert judges than TPBL projects. At a national level, TPBL generated 172 projects in 11 instances, obtaining 12 awards. DTPBL produced 61 projects in seven instances, and student work was recognized with 21 awards. At a global level, student work created with TPBL was never recognized, while student projects generated using DTPBL received seven recognitions in three participation instances. This study provides evidence that a Design Thinking Project-Based Learning (DTPBL) approach can be a successful pedagogical strategy to enhance students' creative skills and produce innovative design solutions.

KEY WORDS

Engineering Pedagogy; Innovation; Design Thinking; Project-Based Learning; Capstone Course

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INTRODUCTION

Designing is hard, teaching how to design is even harder [1]. The activity of designing requires the use of most cognitive dimensions (i.e., remembering, understanding, applying, analyzing, evaluating, and creating). A revised version of Bloom's taxonomy defines the cognitive process of creating, the most complex cognitive activity, as "putting elements together to form a novel, coherent whole or make an original product" [2]. Over the years, the authors have noticed that packaging engineering students find the creation and development of new concepts for packaging systems challenging. Many students struggle with achieving good levels of innovation in their design proposals. The root cause of the problems may be related to different stages in the design process; difficulties building empathy, rigid problem-framing, narrow exploration of different design solutions, and lack of in-depth exploration of each solution.

From a cognitive view, design activities are problem-solving situations: designers have to produce a solution that should fit specific functions and satisfy different requirements and constraints [3]. This problem-solving process in design has been described as grounded on an iterative dialectic between framing and solving a problem [4]–[7]. During problem framing, designers refine design goals and specifications, and with doing so, reformulate their mental representation of the problem. During problem-solving, designers elaborate solutions and test them against different criteria and constraints. Consequently, a combination of convergent and divergent thinking is needed to continue the iterative dialectic.

Prior research has shown that the treatment of design problems is different depending on the level of expertise of the designers and their occupational group. When comparing how novel and expert designers approach design problems, prior research shows that the cognitive treatment of data is performed differently depending on the designers'

level of expertise [8]–[10]. Experts have hours of deliberate practice and training and can engage in analogy-making to solve the design problem. In contrast, novice designers have few reference cases to deal with and tend to have a much more restricted space of research of innovative ideas. Research comparing learning preferences between students in design and design-related disciplines has shown that science and technology students tend to use convergent thinking, a logical and analytical approach towards a right answer [11]. This type of thinking, which moves towards the known and the specific, does not seem to be prolific in idea generation and creativeness. Therefore, tools that facilitate the search for ideas can be of great value to novice designers in scientific and technological fields.

When evaluating the quality of a design, the creativity of the design is one of the most important criteria. As Dieter Rams suggested in his ten principles for good design, good design is always innovative [12]. However, research of creativity in the design process has shown that certain kinds of information in the problem data tend to spur a similar creative concept [6]. In other words, there are early ideas that are easy steps in originality. The use of tools that encourage continuous and iterative improvement, such as those used in Design Thinking approaches, can reveal hidden needs and opportunities for designers and help them move beyond these obvious ideas.

The use of alternative pedagogical approaches in engineering design has been strongly suggested in the last fifteen years [1], [13]–[21]. In the United States, since *The Engineer of 2020* report [13] was published, many programs have aspired to prepare their students to develop skills in human-centered design, learn research skills such as prototyping and testing, develop creativity and adaptability skills through design thinking, and interact with multiple disciplines and backgrounds through teamwork [22], [23]. A national initiative, The Mudd Design Workshop series, has created a prolific forum for sharing

experiences and discussing design competencies that should be taught at engineering programs [14]. At a global level, the O-CDIO (Observe, Conceive, Design, Implement, Operate) initiative aims to incorporate human-centered design approaches and system thinking into the CDIO framework [19].

Initiatives to implement Design Thinking tools within engineering courses have also been reported [15], [16], [18]. Zoltowski *et al.* used phenomenography to develop an outcome space to describe the ways in which engineering students experience human-centered design [16]. Mohedas *et al.* examined how engineering students use ethnographic research techniques and suggested areas where pedagogical effort should be placed. Researchers found that students struggled with conducting effective interviews, recognizing opportunities to involve stakeholders, synthesizing large amounts or conflicting information, and identifying the correct stakeholders [18]. Oehlberg *et al.* described the impact that multidisciplinary collaboration experiences have on students and, among others, concluded that these experiences help students communicate better with their collaborators in their careers [15].

Other researchers have shed some light on the topic of student creativity in engineering courses [17], [24]. After analyzing a sample of engineering courses to identify evidence of pedagogy for creativity, Daly *et al.* suggested that further instructional techniques are required to avoid premature closure, to teach divergent thinking skills, problem exploration, and increase reflection [17]. Similarly, Genco *et al.* found that freshman engineering students can be more innovative than senior students. Authors suggest that additional studies need to be done to investigate the effect of design curricula and skill acquisition on students' innovation capability [24]. Mabogunje *et al.* even argued that Design Thinking is ready to become a foundational science of engineering programs alongside traditional subjects such as physics, chemistry, and biology [25].

Still, many current pedagogical practices in disciplines that require problem-solving design-oriented skills (e.g., engineering, architecture, packaging, marketing) seem to assume that good design outcomes will happen just by integrating knowledge in project-based learning (PBL) models. As Dym *et al.* suggested more than ten years ago, there is a general feeling that “the intellectual content of design is consistently underestimated” [1].

The underlying hypothesis of this study is that creativity and innovation of student work in engineering design courses can be improved by developing and providing them with a *Design Thinking Project-Based Learning* (DTPBL) model. This hypothesis was tested and validated. The results of the process, the quality of the packaging system designs, was conceived of as a criterion which determines the success of the process.

How is Packaging Taught at the College Level in the United States?

In the United States, the discipline of packaging is taught in several higher education institutions. The programs are housed in a wide diversity of colleges such as business, art and design, agriculture and natural resources, engineering, technology, and applied science and technology to name a few (Table 1). Regardless of their alma mater, graduates from these programs will most likely end up with *packaging engineering* job titles.

Michigan State University (MSU) became the first university in the world to offer a Bachelor of Science degree in Packaging, beginning in 1952, and the first to create a dedicated school for the field. Similar programs followed in other universities adopting curriculum models similar to those developed at MSU [26]. Historically, packaging curricula have mainly been based on a “technology/science” model. A typical curriculum includes both packaging and non-packaging courses. The latter category includes courses in the areas of arts and humanities, communication, mathematics, statistics, physics, chemistry, life sciences, and business. An

analysis of packaging courses in current curricula of baccalaureate degrees in packaging at major American institutions reveals the following six areas of study:

- Packaging design (e.g., 2D design, 3D design, CAD systems, prototyping, innovation, development, pre-press software, prototyping).
- Packaging materials (e.g., polymers, metals, glass, composites, fiber-based, material testing).
- Packaging technology (e.g., machinery, converting, manufacturing, research).
- Packaging for specific industries and special topics (e.g., foods, perishables, pharmaceuticals, medical devices, regulations, seminar, cooperative education experience, internships).
- Packaging and supply chain (e.g., supply chain, distribution packaging, protective packaging, packaging performance testing).
- Packaging fundamentals (e.g., introduction to packaging, packaging fundamentals, principles of packaging, basic skills, orientation, career preparation).

Based on current course catalog information, the percentage of units of required packaging courses that fall within each of these six areas for each packaging program was calculated (Figure 1). It can be seen that, although programs vary on their focus, design-related courses are present in all programs with a significant occurrence ranging from 17% to 61%. On average, 28% of the required packaging courses are design-related. The average percentage drops to 25% if the Fashion Institute of Technology's program is excluded. This is the only packaging program housed in an Art and Design Department and focuses heavily on design. Still, design-related courses would rank first on average. Based on this overview, it can be inferred that design skills are considered to be a fundamental part of the training of packaging professionals.

The Packaging Innovation Problem: A Wicked Problem

Reference to design problems as wicked problems was first formulated by Rittel in the 1960s [27]. The first published report defined wicked

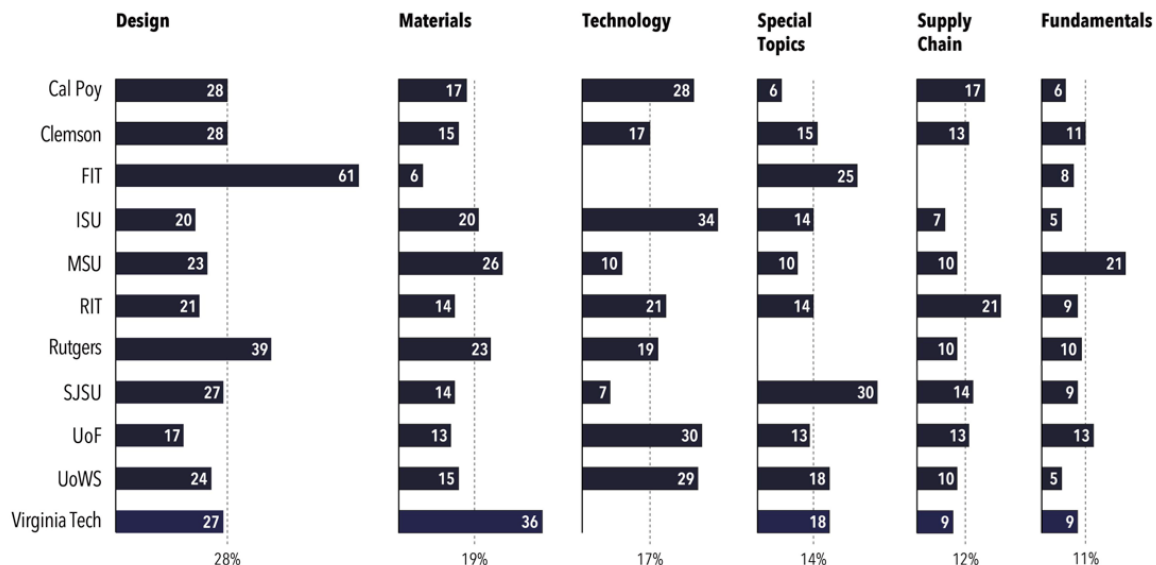


Fig. 1: Percentage of units of required packaging courses that fall within the categories of design, materials, technology, special topics, supply chain, and fundamentals for each packaging program in the United States. Averages across all programs are highlighted on the bottom of the chart.

Table 1: Major institutions in the United States offering degrees in the field of packaging, listed in alphabetical order.

University	College	Undergraduate Degree	Graduate Degree
California Polytechnic State University (Cal Poly)	Business	BS in Industrial Technology and Packaging, Packaging Concentration	MS in Packaging Value Chain
Clemson University	Agriculture, Forestry and Life Sciences	BS in Packaging Science	MS in Packaging Science
Fashion Institute of Technology (FIT)	Art and Design	BFA in Packaging Design	N/A
Indiana State University (ISU)	Technology	BS in Packaging Engineering Technology	N/A
Michigan State University (MSU)	Agriculture and Natural Resources	BS in Packaging	MS in Packaging
Rochester Institute of Technology (RIT)	Applied Science and Technology	BS in Packaging Science	MS in Packaging Science
Rutgers University	Engineering	BS in Packaging Engineering	MS in Packaging Engineering
San Jose State University (SJSU)	Applied Sciences and Arts	BS in Nutritional Science, Packaging Concentration	N/A
University of Florida (UoF)	Engineering	BS in Biological Engineering, Packaging	N/A
University of Wisconsin Stout (UoWS)	Science, Technology, Engineering, Mathematics and Management	BS in Packaging	MS in Packaging
Virginia Tech	Natural Resources and Environment	BS in Packaging Systems and Design	N/A

problems as a “class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing” [28]. In Rittel’s view, most design problems are indeterminate, as there are no definitive conditions or limits to them, they are ill-defined problems and therefore, wicked problems.

Buchanan provided a practical example [7]. A good design brief will include requirements and constraints to be considered in resolving the design problem. However, it will not specify in great detail the particular features of the solution, as this would take the “wickedness” out. Removing the wickedness could seem like a good idea, but in practicality, removing the “wickedness” would narrow the possibility of innovative outcomes.

Packaging may often be associated with boxes or waste, but in reality, packaging systems operate at different levels (i.e., primary, secondary, tertiary) and affect numerous stakeholders whose needs are often conflicting (i.e., end users, retailers, converters, manufacturers, fillers, distributors, regulators) [29]. Generating innovative design systems in packaging is a complex task. It requires understanding and considering a broad diversity of factors such as market opportunity, consumer insights, three-dimensional structure, functionality, aesthetic appeal, communication, product protection, materials, manufacturing processes, supply chain and distribution, sustainability, regulations, and cost.

Therefore, a packaging design problem could be considered a wicked problem, in which the packaging design engineer has to perform trade-offs and balancing acts to reach a good solution. A Design Thinking approach in packaging engineering design can provide useful tools to tackle this type of problems effectively.

Design Thinking Models

Design Thinking can be defined as a human-centered discovery process, followed by iterative cycles of prototyping, testing, and refinement [30]. Design Thinking models started as a way of explaining how designers think and operate, and have become effective and unified frameworks for innovation that connect creative thinking, technology, and business [30]–[33].

Early references on multiphase creative processes, in general, include the work of mathematician Henry Poincaré (1924) [34] and social psychologist Graham Wallas (1926) [35]. Wallas proposed a five-stage model (i.e., preparation, incubation, intimation, illumination, and verification) pondering three levels of subject awareness (i.e., consciousness, fringe consciousness, and non-consciousness) [35], [36]. In the late sixties, the work of Herbert Simon delineated one of the first formal models of the design thinking process [37]. Simon’s model was influential in shaping current Design Thinking models.

There are many variations of Design Thinking models. A brief explanation of the most significant ones and their creators are provided herein:

- *3Is*: Developed by design agency IDEO in 2001 in the context of social innovation. The model encompasses three areas (i.e., Inspiration, Ideation, and Implementation) and specific activities for each of them [30].
- *HCD*: The original *HCD* model was originally based on three areas of action (i.e., Hearing, Creating, and Implementing) [32] but its most updated version relies on three main processes, the ones used by the *3Is* model. This model synthesizes IDEO’s vast experience in human-centered design processes and it can be seen as an evolution of the *3Is* model. *HCD* relies on seven mindsets (i.e., Empathy, Optimism, Iteration, Creative Confidence, Making, Embracing Ambiguity, and Learning from Failure) and numerous tools that are offered through a website (www.DesignKit.org) and a free book, all overseen by IDEO [38].

- *HPI Stanford*: Developed at the Hasso Plattner Institute at Stanford University (United States) around 2005 with strong influence from design consultancy IDEO's co-founder David Kelley. The model includes five steps or modes: Empathy, Define, Ideate, Prototype, and Test [39].
- *HPI Potsdam*: A variation of the previous model developed at the Hasso Plattner Institute at University of Potsdam (Germany). The model comprises six steps: Understand, Observe, Point of View, Ideate, Prototype, and Test [40].
- *4D or Double Diamond*: Created by the British Design Council around 2005. It consists of four phases: Discover, Define, Develop, and Deliver. Unlike the other models, it visually shows the divergent and convergent stages of the design process [41].
- *SDT*: The Service Design Thinking model has four phases: Exploration, Creation, Reflection, and Implementation. One important difference with the other models is that the outcome is a process, not a finished product [42].
- *Evolution 62*: Developed as part of the D-THINK project with the objective of applying it to education and training. The model is structured in six phases: Emergence, Empathy, Experimentation, Elaboration, Exposition, and Extension [43].

The methodological approach for this study was based on the *HPI Stanford* five-stage model [39]. Each of its phases is very clear and can be taught and communicated easily to students in design-related disciplines. The five modes have their objectives and requirements, and they can be performed iteratively and not necessarily in sequential order, namely:

1. Empathize: The process of understanding the human's needs and building empathy to discover more profound needs.
2. Define: The process of framing and determining a unique problem from a large, unorganized set of information.
3. Ideate: The process of idea generation.
4. Prototype: The process of developing models intended to elicit qualitative and quantitative feedback.
5. The process of evaluating and incorporating feedback.

Regardless of the model used, several characteristics make Design Thinking an excellent tool for solving *wicked problems* [7]. In general, Design Thinking can be characterized by being iterative, cross-disciplinary, human-centered, prototype-driven, and having alternating phases of generation and selection (i.e., convergent and divergent thinking) [40].

OBJECTIVES

The underlying hypothesis of this study is that creativity and innovation of student work in design-related disciplines can be improved by developing and providing students with a *Design Thinking Project-Based Learning* (DTPBL) framework.

More specifically, it is hypothesized that packaging design quality and innovation levels would improve when implementing a methodology that includes the following characteristics:

- Cross-disciplinary collaboration: The use of teams with educational background diversity will foster innovation that happens at the intersection of disciplines.
- Human-centered: Students will be able to discover opportunities and problems by focusing on stakeholders' needs.

- Iterative: The use of a systematic iterative process of divergent and convergent thinking with continuous use of physical prototyping will improve the variety and depth of the design solutions.
- Experiential: The overall collaboration will provide a fulfilling learn-by-doing experience.

METHODS

Cal Poly Packaging Program had been using a traditional project-based learning (PBL) approach to teaching packaging design in classrooms until 2014. The experience presented in this article aimed to improve the pedagogical approach by incorporating essential elements of Design Thinking to a traditional PBL approach. Both PBL approaches share core characteristics such as providing hands-on experience through a quarter-long team collaboration that involves the application of knowledge in the packaging field to solve a problem, providing resources (i.e., physical space, prototyping equipment, material substrates), and encouraging the use of prototyping.

However, in *Traditional Project-Based Learning* (TPBL), packaging design is assumed to be a consequence of combining software skills, materials knowledge, and manufacturing processes to solve a problem. In TPBL, projects are framed in isolation within one discipline (i.e., packaging), and the project development is envisioned linearly, with a problem-framing phase and a problem-solving phase. Contrary, in *Design Thinking Project-Based Learning* (DTPBL), packaging design is understood as a willing and active search for solutions that attempts to fulfill stakeholders needs. Projects are framed in a collaboration between two disciplines (i.e., graphic design and packaging), and the project development is envisioned as an iterative model with co-evolution of problem/solution spaces [6].

The following sections describe the different steps that were taken to implement the DTPBL approach, namely:

1. Establish a cross-disciplinary partnership between courses.
2. Devise a methodology based on a Design Thinking model.
3. Secure support resources to students and faculty.
4. Implement the pedagogical approach multiple times.
5. Validate the results using external, independent actors.

Cross-Disciplinary Partnership

Working at the intersection of disciplines tends to create a synergy that is difficult to achieve by working as separate silos [44]. The first step included finding professors with the adequate, diverse backgrounds that were willing to collaborate. The partnership for implementing the new pedagogical approach was established between professors at California Polytechnic State University (Cal Poly); one professor from the Art and Design Department (College of Liberal Arts), and two professors from the Industrial Technology and Packaging Area (Orfalea College of Business). These professors teach several courses in the Graphic Design Concentration (Art and Design Department), and Packaging Concentration (Industrial Technology and Packaging) respectively.

The Graphic Design Concentration (Art and Design Department) emphasizes creative problem solving while providing a solid foundation in design principles, typography, branding design, illustration, user interface design, and art and design history. An important focus of the concentration is the preparation of a professional portfolio that showcases the creative and conceptual design abilities of the students [45].

The Packaging Concentration (Industrial Technology and Packaging Area) offers a holistic approach to the entire packaging value chain and includes disciplines such as engineering, material science, design, and business. It provides students with a solid foundation on packaging materials, sustainability, supply chain management and logistics, and packaging design [46].

Cal Poly operates in a quarter system; the academic year consists of Fall, Winter, and Spring quarters. The cross-disciplinary partnership was, therefore, a 10-week long collaboration between two courses from different colleges offered during the same quarter. Graphic design students and packaging students worked in teams to develop a fully functional innovative packaging system. The partnership was established between different combinations (see Implementation section) of four senior-level courses (Table 2).

Methodology

The authors devised and managed the DTPBL approach that, given its flexibility, was adapted to solve multiple specific design problem statements for each collaboration. Table 3 summarizes DTPBL approach's critical elements and characteristics.

Teams

Cross-disciplinary teams were formed during the first week of instruction. All teams were composed of both packaging and graphic design students. The size of the teams ranged between three and six members. This variability in the team size was due to different enrollment sizes in the courses between quarters.

Professional roles by disciplines were assigned to the team members, similar to the roles students may have in industry positions once they graduate. Discussions about the overall idea of the project and integration were taken as a team, but once the concepts had been defined collectively, packaging

students worked primarily on the structure, technological processes, and materials choices, while the graphic designers developed graphics concepts.

Team members were asked to share contact information with their teammates to enable interaction beyond laboratory hours and achieve fluid, internal communication.

Lecture Support

The course structure consisted of two lecture meetings and one lab meeting per week (Table 2). As a general rule, all lecture support activities were linked to the quarter-long packaging innovation project. Researchers have reported adverse effects of diverting students' focus to activities not linked to the course's project [19], [23]. Lectures were offered by discipline; this means that graphic design students and packaging students attended their course regular lectures separately.

Lecture topics and activities were synchronized with each phase of the project. They focused on technology (e.g., history, materials, manufacturing methods, packaging processes), design considerations (e.g., design thinking, development processes, packaging value chain, sustainable design, intellectual property, regulations), and tools (e.g., retail audit, ethnographic research, concept generation and brainstorming techniques). Some lectures included case studies both from industry and from previous student projects. Guest speakers from industry brought their own experience to the classrooms and presented their case studies. In-class team activities were used for problem reframing and concept generation for the quarter-long project.

Table 2: Courses used for cross-disciplinary partnerships.

Course ID	Catalog Description	Units	Mode of Instruction per Week
ART 400	Individual investigation, research, studies, or surveys of selected problems.	2	Based on project needs
ART 437	Advanced graphic design. The creation of basic 3-D structures, and the application of graphics in 3-D environments (such as package design and retail environment graphics). Emphasis on integrative communication activity of all elements including: color, graphics, 3-D forms, typography, and constructions, and includes market research.	4	Lec+Lab: 6 hrs
ITP 408	Physical and chemical properties, manufacture, conversion and use of paper, paperboard, corrugated board and related components. Design, use and evaluation of packages made from these materials. Survey of tests and procedures for paper-based packaging materials and packaging products following ASTM, TAPPI, and ISO standards.	4	Lec: 3 hrs Lab: 3 hrs
ITP 485	Integrative approach to developing new packaging systems by balancing the needs of the different value chain stakeholders. Interplay of package design for end-users, marketing, manufacturing, distribution, and disposal. Class project focuses on cross-disciplinary collaboration, design thinking, discovery, and disruptive innovation.	4	Lec: 3 hrs Act: 2 hrs

Lec: Lecture; Lab: Laboratory; Act: Activity

ART 400 Special Problems for Advanced Undergraduates

ART 437 Graphic Design III

ITP 408 Paper and Paperboard Packaging

ITP 485 Packaging Development

Table 3: Elements and critical characteristics of the Design Thinking Project-Based Learning (DTPBL) approach.

Element	Critical Characteristics
Teams	<ul style="list-style-type: none"> ● Cross-disciplinary ● Professional roles by disciplines ● Highly collaborative
Lecture Support	<ul style="list-style-type: none"> ● Synchronized with lab activities ● Discipline-based ● Focus on technology, design, and tools ● Case studies discussions ● In-class team activities linked to project ● Guest speakers from industry
Project Guidelines	<ul style="list-style-type: none"> ● Detailed ● Replicate professional product development phases ● Phase-gate process ● Enabled weekly assessment
Lab Synchronization	<ul style="list-style-type: none"> ● Overlapping lab hours for ITP and ART courses ● Continuous use of ITP and ART lab spaces ● Open use of equipment ● Common meeting space
Face-to-face Weekly meetings	<ul style="list-style-type: none"> ● Faculty meet with teams weekly ● Individual accountability ● Personalized feedback ● Keeps team focus ● Effective decision making
Intermediate Deliverables	<ul style="list-style-type: none"> ● Reports ● Sketches ● Low-fidelity (lo-fi) and medium-fidelity (med-fi) prototypes ● Mood boards ● Graphics concepts
Final deliverables	<ul style="list-style-type: none"> ● High-fidelity (hi-fi) prototype ● Final report
Grading	<ul style="list-style-type: none"> ● Discipline-based ● Grading rubric detailed for each phase and aspect of the project
Peer Evaluation	<ul style="list-style-type: none"> ● Confidential ● Announced and available from day one ● Each student provides feedback about his/her team ● Affects final individual project grade

Project Guidelines

The project was divided into five phases: research, opportunity identification, concept exploration, concept refinement, and final concept (Figure 2 and Table 4). These phases were based on a generic professional packaging development process [29]. The five phases were as follows:

- **Research:** The primary objective of the research phase was to gather information and perform analyses. This phase had two deliverables: a retail audit report and an ethnographic research report.
- **Opportunity Identification:** This phase identifies actionable problems. At the end of the phase, two deliverables were due: an opportunity identification report and a design brief.
- **Concept Exploration:** The goal of this phase was to generate and explore a large number of innovative concepts based on the design brief.

Throughout the phase, sketches, low-fidelity (lo-fi) prototypes, mood boards, and graphics concepts were delivered.

- **Concept Refinement:** During this phase, feedback from testing was used to refine lower resolution (lo-fi models) models into increasingly complex ones (med-fi models). Particular attention was paid to good sustainability practices and their impact on packaging materials and technology selection, stakeholder-value, palletization, distribution, affordance-based design [47], and overall communication. Deliverables for this phase include refined sketches and graphic concepts, 3D digital models, and medium-fidelity (med-fi) prototypes.
- **Final Concept:** The main goal of this phase was to deliver a high-fidelity (hi-fi) prototype and a final report.

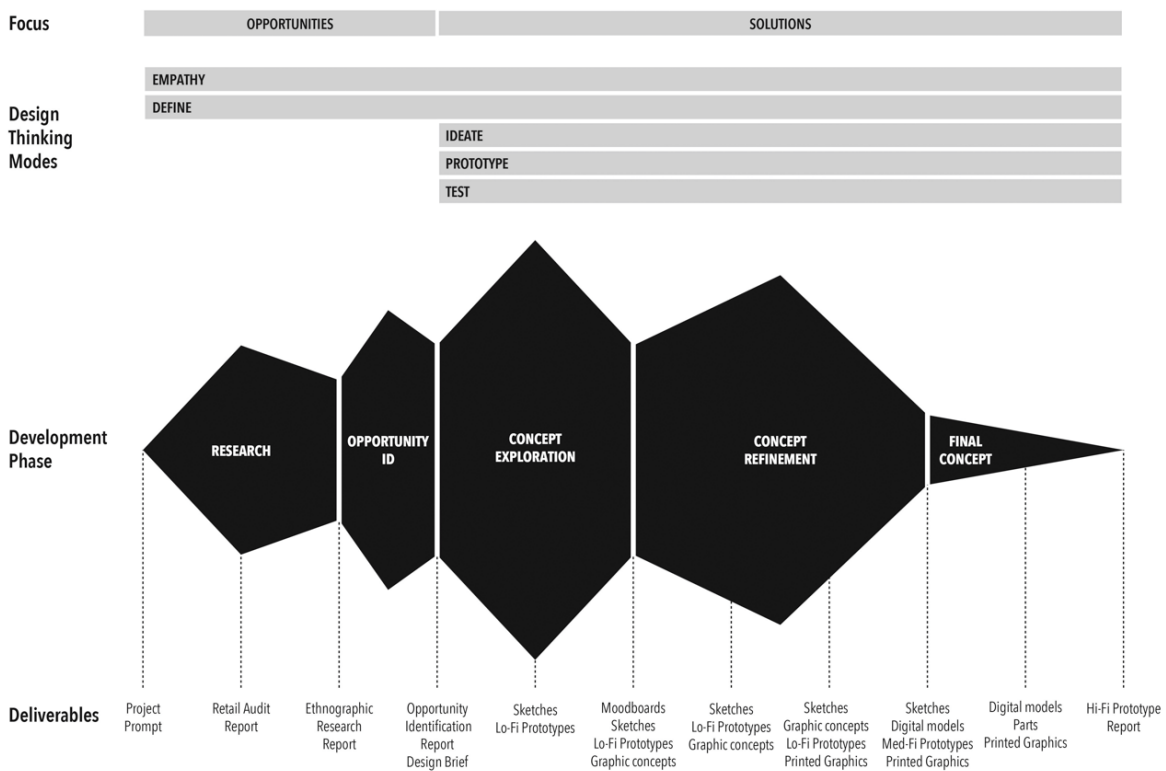


Fig. 2: Project development phases, design thinking modes, deliverables, and duration. The broadening and narrowing of each development phase's space represent the creation of choices (diverging) and the making of decisions (converging) respectively.

Table 4: Project phases, design thinking modes, deliverables, and duration.

Phase	Objectives	Design Thinking Modes	Deliverables	Duration
Research	To identify opportunities and gather information regarding the product category, current packaging, consumer insights, user characteristics, and market trends. This information helps define the design brief and marketing plan.	Empathize Define	<ul style="list-style-type: none"> ● Retail Audit Report ● Ethnographic Research Report 	2 weeks
Opportunity Identification	To identify one actionable problem statement that focuses on the insights uncovered in the research phase.	Empathize Define	<ul style="list-style-type: none"> ● Opportunity ID Report ● Design Brief 	1 weeks
Concept Exploration	To explore and generate ideas through brainstorming sessions and prototyping with the design brief and research information at hand. The goal is to generate a large number of ideas for innovative package concepts.	Empathize Define Ideate Prototype Test	<ul style="list-style-type: none"> ● Sketches ● Mood boards ● Graphics concepts ● Lo-fi prototypes 	2 weeks
Concept Refinement	To test physical prototypes and incorporate feedback in an iterative process that results in the refinement of lower resolution models into increasingly complex and resolved ones.	Empathize Define Ideate Prototype Test	<ul style="list-style-type: none"> ● Sketches ● 3D digital models ● Refined graphics concepts ● Med-fi prototypes ● Printed graphics 	3 weeks
Final Concept	To create final deliverables.	Empathize Define Ideate Prototype Test	<ul style="list-style-type: none"> ● Hi-fi prototype ● Report 	2 weeks



Fig. 3: Students in a cross-disciplinary lab meeting.

Each phase was distinct and separated from the next phase by a decision point. The decision points happened during the weekly face-to-face lab meetings. This approach helped in identifying problems and assessing progress. It also reduced the complexity of what might look like an overwhelming challenge into a straight-forward approach.

The phases of research and opportunity identification were mainly focused on exploring and selecting opportunities. The remaining phases were focused on generating and selecting design solutions for those opportunities. When the focus was on finding and selecting opportunities the predominant Design Thinking modes used were empathy and define. When generating and refining solutions, all five Design Thinking modes were involved (i.e., empathy, define, ideate, prototype, test).

It is important to highlight that project development phases and Design Thinking modes are separate concepts. Development phases are sequential; however, Design Thinking modes are used cyclically throughout the project. Modes can be conceived of as mindsets that the designer uses to

switch from divergent to convergent thinking and vice versa. Figure 2 shows a graphical representation of the divergent and convergent thinking in each phase. The broadening and narrowing of each development phase's space represent the creation of choices (diverging) and the making of decisions (converging) respectively.

Detailed project guidelines were provided the first week of instruction and included objectives, project phases, important deadlines, intermediate deliverables, grading rubric, and final deliverables descriptions.

Lab synchronization

It is vital for the success of cross-disciplinary collaboration to create a shared space and time where the different team players meet [44]. For such reason the laboratory schedules of each ITP/ART pair of courses (e.g., ITP 408/ART 437, ITP 485/ART 400) were synchronized, both laboratories were scheduled the same day at the same time (Figure 3). Previous to the beginning of the quarter, instructors of both courses agreed on a common schedule based on the project guidelines to designate when the ITP and ART students

would meet. Students were able to use the equipment and meeting space of either course.

Our first experience with these collaborations did not account for laboratory synchronization between courses, and the collaboration proved to be much more challenging. Once laboratories were synchronized, students had the space and time to meet every week for at least three hours. By synchronizing laboratory hours for both courses, and providing a continuous use of both laboratory spaces and open use of equipment and meeting space, teams had not only a weekly check-point to look forward to but also a weekly opportunity to build on each other's ideas and to produce joint work.

Face-to-Face Weekly Meetings

The idea behind these meetings was to create an environment that stimulates the sharing of ideas. Each team met weekly with faculty during 20/30 minutes. Depending on the phase of the project, these meetings included the whole team (packaging and graphic design students) and all faculty, or just one of the disciplines and their respective faculty. Faculty posed questions to the teams to make them reflect on their decision-making process and provided technical advice.

The common objective of the team members was to get their project done well and on-time. Every weekly meeting was a step towards that end and was treated as a mini-project in itself. During these meetings, students presented the work that had been accomplished during the week, feedback was provided by faculty members and other team members, and a brainstorming session typically took place to generate new ideas to move forward the project. These meetings typically involved verbal conversations, idea drawing, and rough prototype building.

Many Millennials already have mastered the high-tech communication skills, but usually lack many of the basics of face-to-face team communication [48]. Students were asked to spend time to prepare for the meetings, gather their thoughts and establish the purpose and the desired outcome. While in the meeting, students

were asked to be present, attentive, and to deliver information concisely and consistently. Providing this 20/30-minute space, where members are encouraged to resist the urge of multi-tasking, be clear-minded, present, and provide full participation, enabled for personalized quality feedback, kept the team's focus, and worked as a tool for effective decision making.

Grading

Grading was discipline-based, each instructor evaluated her/his own students' work. However, feedback was given during weekly meetings by all professors to all students regardless of their discipline. A detailed grading rubric was used to assess each phase and aspect of the project.

Intermediate Deliverables

Intermediate deliverables included short reports (e.g., retail audits, consumer insights, opportunity identification reports, design briefs), sketches, 3D digital models, graphics concepts, and lo-fi and med-fi physical prototypes (Figure 4). Lo-fi prototypes are quick mockups used to make general decisions regarding dimensions, form, configuration, and working principles. This practice is also known as quick-and-dirty prototyping [49]. Med-fi prototypes are more detailed than lo-fi prototypes and combine all elements in the packaging system, including graphics concepts. Intermediate deliverables served as milestones and were used for grading purposes.

Final Deliverables

Final deliverables included a hi-fi prototype of the packaging system with graphics (Figure 5) and a final report. Hi-fi prototypes are detailed physical models with applied final graphics that have a high level of resemblance with the manufactured retail package.

Table 5: Courses combinations used for cross-disciplinary collaborations between 2015 and 2018.

Quarter	Courses	
	Industrial Technology and Packaging	Art and Design
Winter 2015	ITP 408	ART 400
Spring 2015	ITP 485	ART 437
Winter 2016	ITP 408	ART 400
Spring 2016	ITP 485	ART 437
Winter 2017	ITP 408	ART 437
Spring 2017	ITP 485	ART 400
Winter 2018	ITP 408	ART 437
Spring 2018	ITP 485	ART 400

Peer Evaluation

In order to ensure a fair and accurate assessment of individual student contributions, each team member had to complete a peer evaluation form [50]. These evaluations were confidential, announced on the first meeting day, and were completed by each student on the final exam's day (i.e., after the project has been completed in full). The evaluation allowed team members to assess other members of the team as well as themselves. As a team, each project received a final grade. However, the individual performance of each student in the team had an impact on their individual's project grade. Peer evaluation forms were successful at providing students with a sense of individual accountability.

Resources

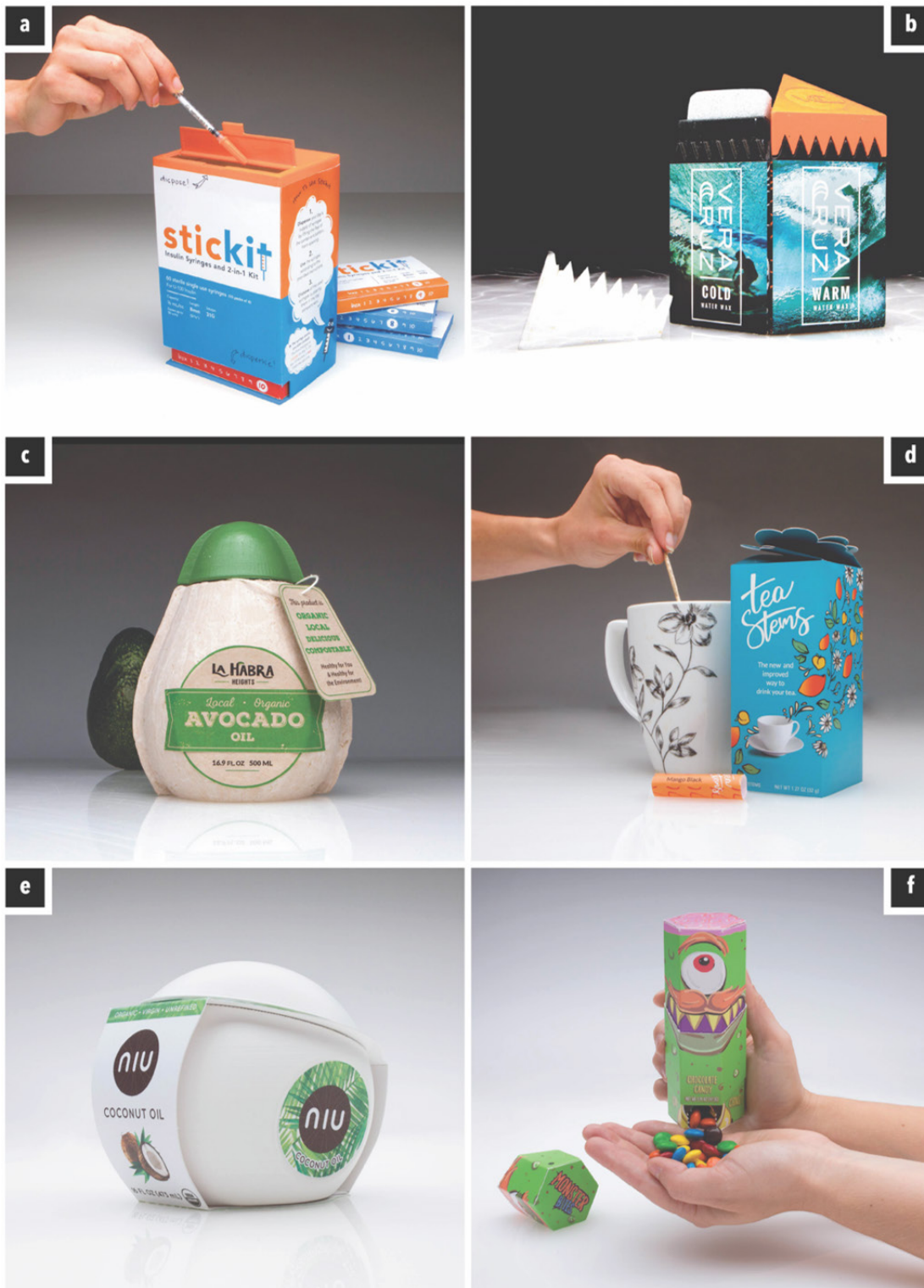
The collaborations between ITP and ART courses relied on three types of physical resources:

- Meeting space: each course of the partnership had their own assigned classroom (Packaging Design Lab and Art and Design Lab), but at any given moment both courses could meet in any of the two labs. Besides, each department had their computer lab. Software available to students included computer-aided design (CAD) programs (e.g., ArtiosCAD[®], SolidWorks[®]) and illustration software (e.g., Adobe[®] Illustrator, Adobe[®] Photoshop).
- Prototyping support: equipment for prototyping included an inkjet plotter, three desktop 3D printers (Ultimaker[®]), a thermoformer, and a cutting table (Kongsberg 1930). Prototyping tools and substrates such as paperboard, corrugated fiberboard, and plastic sheets were available to all students.
- External partners: comping services, a professional photographer, and Cal Poly's Graphic Communication Department printing resources were used when projects required resources beyond the collaboration capabilities.

Fig. 4: Examples of deliverables: a) Lo-fi prototype for form study, b) Med-fi prototype, c) Hi-fi prototype, d) Sketches for structure, e) Sketches for graphics.



Fig. 5: Examples of final hi-fi prototypes: a) SticKit, b) Vera Cruz, c) La Habra, d) Tea Stems, e) Niu, f) Monster Bites.



Implementation

DTPBL was implemented in eight quarters between 2015 and 2018 (Table 5). These eight instances represent collaborations between students and faculty of a packaging course and a graphic design course. They are referred to as Winter and Spring collaborations.

Winter collaborations were focused on packaging innovation using paperboard. During these collaborations, a quarter-long project was developed by cross-disciplinary teams of students enrolled in the ITP 408 Paper and Paperboard Packaging course and graphic design students enrolled in the ART 437 Graphic Design III course (on Winter 2017 and 2018) and ART 400 Special Problems for Advanced Undergraduates (on Winter 2015 and 2016).

Spring collaborations were focused on packaging innovation in general, without any constraint regarding packaging materials. During these collaborations, a quarter-long project was developed by cross-disciplinary teams of students enrolled in the ITP 485 Packaging Development course and graphic design students enrolled in the ART 400 Special Problems for Advanced Undergraduates course (on Spring 2017 and 2018) and ART 437 Graphic Design III (on Spring 2015 and Spring 2016).

External Validation

Validating a pedagogical approach to teaching packaging design is challenging and may take years of continuous application. The assessment of creativity in design work typically relies on expert judges [51]. One way to measure the effect on the quality of the work is through external student design competitions. These competitions reward feasible design innovation and creativity. In particular, the authors used design competitions in which Cal Poly Packaging Program students had been participating for a while, so it was possible to make a comparison in performance between both pedagogical approaches, TPBL and DTPBL.

Cal Poly Packaging Program has regularly been participating since the early 2000's in three packaging design competitions; namely the Paperboard Packaging Alliance Student Design Challenge (*PPA SDC*), AmeriStar Student Package Awards Competition (*AmeriStar SPAC*), and the World Packaging Organisation WorldStar Student Awards (*World-Star SA*). Cal Poly's entries to these competitions up to 2014 were designed following the TPBL approach. Entries submitted from 2015 until date were designed following the DTPBL approach.

Paperboard Packaging Alliance Student Design Challenge

The *PPA SDC* is organized each year by the Paperboard Packaging Alliance (PPA) and challenges students in leading packaging design programs to show off their design skills, innovative capacity, and knowledge in meeting real-world customer needs and marketing scenarios. Undergraduate students enrolled in packaging, industrial and/or graphic design programs from across North America (United States, Canada, and Mexico) are eligible to enter as an individual or a team. The winning students and schools earn cash prizes [52]. The judging panel changes every year depending on the competition's topic and is typically comprised of five professionals with between 20 to 50 years of experience in the paperboard packaging industry. The entries are judged based on product positioning and marketing, product protection, distinctive functionally, quality of the structure, quality of graphics, materials choice and recyclability, and production feasibility. The competition grants five types of awards: first place, second place, third place, runner-up, and honorable mention or shout-out.

AmeriStar Student Package Awards Competition

The *AmeriStar SPAC* is organized yearly by the Institute of Packaging Professionals (IoPP) and honors the most innovative packages developed by students enrolled in college, university or

vocational/technical school programs (undergraduate or graduate) in the United States [53]. The judging panel changes each year, and typically includes 26-30 packaging industry professionals with a current IoPP membership. *AmeriStar SPAC* winners represent the United States at the *WorldStar SA*. The entries are judged based on innovation, product protection, economics, package performance, marketing, and environmental impact. The competition grants four types of awards: first place, second place, third place, and honorable mention(s).

WorldStar Student Awards

The *WorldStar SA* competition is organized every year by the World Packaging Organisation (WPO) in partnership with packaging organizations across the world [54]. It is an international packaging design competition for undergraduate and graduate students from countries around the world who have won a legitimate local award in their region or country. The competition encourages new and innovative ideas and thinking in

the field of packaging. Entries are scored by a panel of approximately ten international industry professionals based on the degree of innovation including conceptual and technical aspect, sales appeal/graphics in the target country, sustainability aspects relative to the target country, ease of processing/manufacturing, functionality, efficiency, and overall impression. The competition grants three types of awards: winners (i.e., the top three highest scoring entries and save food awards), certificates of merit (i.e., the next ten highest scores), and certificates of recognition (i.e., the balance of entries with a minimum score of 50,01% of the overall marks).

PPA SDC, *AmeriStar SPAC*, and *WorldStar SA* competitions offered good problem prompts to be used in class projects, so the authors designed project guidelines around them for Winter and Spring collaborations. Therefore, Winter quarter collaboration projects were submitted to *PPA SDC*, and Spring quarter collaboration projects were submitted to *AmeriStar SPAC*. *AmeriStar SPAC* winners were submitted to *WorldStar SA*.

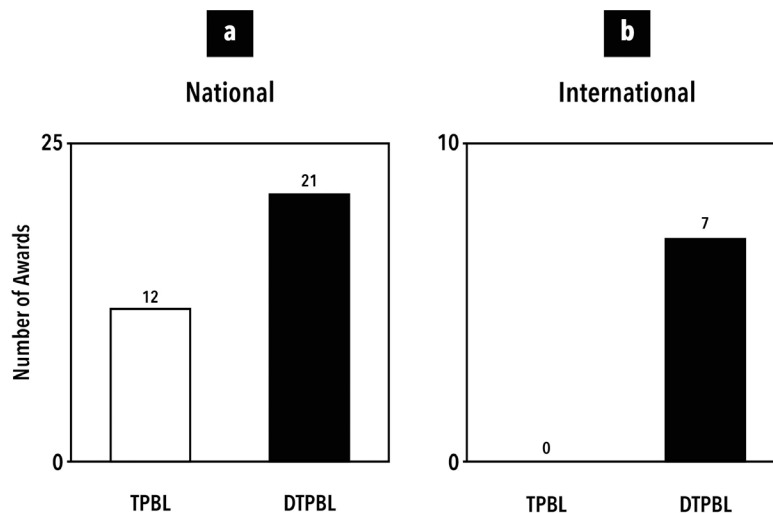


Fig. 6: Total number of awards received by student projects developed under Traditional Project-Based Learning (TPBL) and Design Thinking Project-Based Learning (DTPBL). a) National level (*PPA SDC* and *AmeriStar SPAC*), b) International level (*WorldStar SA*).

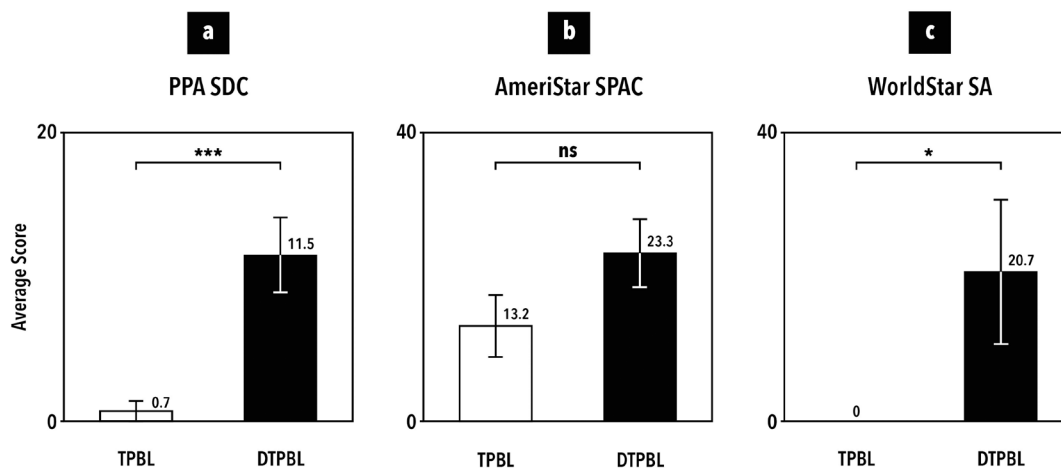


Fig. 7: Comparison of average scores obtained by student projects in three design competitions and developed under Traditional Project-Based Learning (TPBL) and Design Thinking Project-Based Learning (DTPBL). Error bars represent the standard error.

Statistical significance: $ns = p > 0.05$, $* = p \leq 0.05$, $*** = p \leq 0.001$.

DATA ANALYSIS

Data were analyzed using JMP[®] Pro version 14.0.0 (Cary, North Carolina, USA) [55]. A weighted score based on placement was calculated to measure the level of recognition achieved in each competition. Tables 7, 8, and 9 show the weights used to calculate the final weighted scores. Two-sample t -tests were calculated to examine potential differences between these scores for both pedagogical approaches, TPBL and DTPBL.

RESULTS AND DISCUSSION

The comparison between the total number of awards received by DTPBL and TPBL student projects reveals, that despite having been implemented over a shorter period, DTPBL has already yielded a greater number of awards. In other words, DTPBL yielded student work with overall higher levels of innovation, as recognized by independent national and international judging panels (Figure 6 and Table 6). At a national level, TPBL generated 172 projects in 11 instances, obtaining 12 awards. DTPBL produced 61 projects

in seven instances, and student work was recognized with 21 awards (Figure 6a). Nine projects created using DTPBL are awaiting for *AmeriStar SPAC* 2019 competition. At a global level, student work created with TPBL was never recognized, while student projects generated using DTPBL received seven recognitions in three participation instances (Figure 6b).

When comparing weighted scores, the average overall score for DTPBL projects was higher than for TPBL projects for all three design competitions (Figure 7). The differences between approaches for *PPA SDC* and *WorldStar SA* were statistically significant. These scores indicate that DTPBL projects placed higher in competitions and that they were recognized more often. The next sections describe the specifics of each design competition.

Paperboard Packaging Alliance Student Design Challenge

The Paperboard Packaging Alliance keeps detailed records of all participating schools and team members since 2009. This information available on their website [52] was used to draw a comparison

Table 6: Course combinations used for Design Thinking Project-Based Learning (DTPBL), submitted projects, design competitions, and awards received.

Quarter	Courses	Submitted Projects	Design Competition	Awards Received		Number of Awards
				Description	Qty.	
Winter 2015	ITP 408 ART 400	10	PPA SDC '15	First Place Honorable Mention	1 1	2
Spring 2015	ITP 485 ART 437	12	AmeriStar SPAC '16	First Place Second Place Third Place Honorable Mention	1 1 1 1	4
		4 ^a	WorldStar SA '16	Certificate of Merit	1	1
Winter 2016	ITP 408 ART 400	5	PPA SDC '16	Honorable Mention	2	2
Spring 2016	ITP 485 ART 437	9	AmeriStar SPAC '17	First Place Second Place Third Place Honorable Mention	1 1 1 1	4
		4 ^a	WorldStar SA '17	Winner Certificate of Merit	2 2	4
Winter 2017	ITP 408 ART 437	11	PPA SDC '17	Second Place Runner-Up Honorable Mention	1 1 1	3
Spring 2017	ITP 485 ART 400	8	AmeriStar SPAC '18	Second Place Third Place	1 1	2
		6 ^a	WorldStar SA '18	Save Food Winner Certificate of Merit	1 1	2
Winter 2018	ITP 408 ART 437	6	PPA SDC '18	Second Place Runner-Up Honorable Mention	1 1 2	4
Spring 2018	ITP 485 ART 400	9	AmeriStar SPAC '19	Entries yet to be submitted		

^a These projects are AmeriStar winners or PPA winners

Table 7: Summary of participation in the Paperboard Packaging Alliance Student Design Competition between 2009 and 2018.

Approach	Year	Submitted Projects	Awards Received (Weights)					Weighted Score	Total Submitted Projects	Total Awards Received
			1 st (10)	2 nd (8)	3 rd (6)	RU (4)	HM (2)			
TPBL	2009	7	0	0	0	0	0	0	57	1
	2010	16	0	0	0	0	0	0		
	2011	4	0	0	0	1	0	4		
	2012	7	0	0	0	0	0	0		
	2013	10	0	0	0	0	0	0		
	2014	13	0	0	0	0	0	0		
DTPBL	2015	10	1	0	0	0	1	12	32	11
	2016	5	0	0	0	0	2	4		
	2017	11	0	1	0	1	1	14		
	2018	6	0	1	0	1	2	16		

RU: Runner-Up; HM: Honorable Mention

Table 8: Summary of participation in the Ameristar Student Package Awards between 2011 and 2018.

Approach	Year	Submitted Projects	Awards Received (Weights)				Weighted Score	Total Submitted Projects	Total Awards Received
			1 st (10)	2 nd (8)	3 rd (6)	HM (4)			
TPBL	2011	24	0	0	1	0	6	115	11
	2012	27	0	0	0	0	0		
	2013	25	1	1	0	0	18		
	2014	19	0	1	0	3	20		
	2015	20	0	1	1	2	22		
DTPBL	2016	12	1	1	1	1	28	29	10
	2017	9	1	1	1	1	28		
	2018	8	0	1	1	0	14		

HM: Honorable Mention

Table 9: Summary of participation in the WorldStar Student Awards between 2011 and 2018.

Approach	Year	Submitted Projects	Awards Received (Weights)		Weighted Score	Total Submitted Projects	Total Awards Received
			Winner (10)	CoM (8)			
TPBL	2011	1	0	0	0	1	0
	2012	0	0	0	0		
	2013	0	0	0	0		
	2014	0	0	0	0		
	2015	0	0	0	0		
DTPBL	2016	4	0	1	8	14	7
	2017	4	2	2	36		
	2018	6	1	1	18		

Winner: Top 3 and Save Food Awards; CoM: Certificate of Merit (Top 13)

between editions that took place before and after implementing DTPBL (Table 7).

An independent-samples *t*-test was calculated to compare *PPA SDC* scores of both pedagogical approaches (Figure 7a). A significant increase in performance of students projects developed under DTPBL was found ($t(8)=-4.84$, $p<0.001$). The mean score for the performance of TPBL projects was 0.67 ($sd=1.63$), and the mean score for the performance of DTPBL projects was 11.50 ($sd=4.43$).

During the period in which TPBL was employed, Cal Poly submitted 57 student projects throughout six years of participation (2009-2014). Cal Poly's student entries never met the standards for a top three award. The best, and only, mark achieved was a runner-up at the 2011 competition.

DTPBL was implemented in four instances (2015-2018) and produced 32 student projects. Eleven projects received recognition; this represents 34% of the projects. During this period, entries have placed in the top three on three editions (i.e., 2015, 2017, and 2018), being 2018 the year of most significant success for Cal Poly's students with four entries receiving recognition.

AmeriStar Student Package Awards Competition

The AmeriStar Student Package Awards Competition winners are announced every year at the Institute of Packaging Professionals' website [53]. The full list of winning entries for the last edition can be found in video format at the mentioned website. A list of the winners from 2011 to 2017 can also be found on the organizations' website. Information from the IoPP website, together with Cal Poly's submission records were used to draw a comparison between editions that took place before and after implementing DTPBL (Table 8).

An independent-samples *t*-test was calculated to compare *AmeriStar SPAC* scores of both pedagogical approaches (Figure 7b). The average score of student

projects developed under DTPBL was higher than the average score of projects developed under TPBL, but the difference was found not to be statistically significant ($t(6)=-1.51, p=0.18$). The mean score for the performance of TPBL projects was 13.20 ($sd=9.65$), and the mean score for the performance of DTPBL projects was 23.33 ($sd=8.08$).

Between 2011 and 2015, when TPBL was used as a pedagogical approach, Cal Poly typically had a good record of placing at least one award at the competition. A total of 115 projects were submitted receiving a total of 11 awards. Projects submitted to the 2016, 2017, and 2018 editions were developed using DTPBL. A total of 29 student projects were submitted, ten of which received recognition. After the implementation of the new approach, Cal Poly had a complete sweep for two consecutive years (2016 and 2017), taking all available awards. To our knowledge, no other teaching institution has swept the student competition twice in a row before. More importantly, the increase in overall quality achieved by DTPBL projects allowed Cal Poly to submit more competitive entries to the global competition, *WorldStar SA*, and obtained unprecedented results.

WorldStar Student Awards

This global competition has been held since 2005 until today. It started with only six participating countries; in the 2017 edition, twenty-two countries participated. A comprehensive list of the winners from 2006 to 2017 can be found on different organizations' websites [56], [57]. This information can be used to evaluate the role of American schools in the competition, and to measure the impact that DTPBL has had on the global recognition of Cal Poly's students work.

An independent-samples *t*-test was calculated to compare *WorldStar SA* scores of both pedagogical approaches (Figure 7c). A significant increase in performance of students projects developed under DTPBL was found ($t(6)=-3.45, p<0.05$). The mean score for the performance of TPBL projects was zero ($sd=0$), and the mean for the performance of DTPBL projects was 20.7 ($sd=14.2$).

Before DTPBL was implemented, Cal Poly student projects had never received expert recognition at a global level. After implementation, every year at least one student entry has been recognized as a top 13 in the world. In 2017, all four Cal Poly student entries placed within the top 13 in the world (Table 9).

Cal Poly became the first university in the world to place two top winners in the same competition edition (2017 edition). Other countries have placed more than one winner in the same edition, such as China (2006, 2011), Turkey (2012, 2013), and the United Kingdom (2018), but different institutions submitted these entries. Thanks to the new pedagogical approach, Cal Poly is the American university with most awards at this global competition. A total of seven awards; one save food award in 2018, two top winners in 2017, and a total of four certificates of merit from the 2016, 2017, and 2018 editions. Other American universities have been recognized globally over the years: The University of Wisconsin-Stout received one top winner in 2011, Clemson University received one certificate of merit in 2010, and the University of Cincinnati obtained one certificate of merit in 2011.

CONCLUSIONS

This study provides evidence that a *Design Thinking Project-Based Learning* (DTPBL) approach can be a successful pedagogical strategy to enhance students' creative skills and produce innovative packaging solutions. An external and independent validation process based on the awards received at several national and international packaging design competitions was used to quantify the effect of the implementation. It is difficult to speculate on which factor of the new pedagogical approach contributed most to the boost in student work quality. However, the authors attribute the success to the combination of the following factors:

Cross-disciplinary Collaboration

Multi-disciplinary brainstorming sessions and guidance yielded large numbers of innovative concepts due to the synergy that is created at the intersection of disciplines. The cross-disciplinary environment in the classroom simulated real-life collaborations that are the norm in the industry. Packaging professionals most commonly work as part of a team with professionals with different backgrounds; structural design, graphic design, printing production, marketing, manufacturing, and supply chain.

Human-Centered

Students were able to discover opportunities by focusing on stakeholders' needs. The use of ethnographic research in the early stages led to the unveiling of hidden needs and problems with existing products. This research, together with the retail audits, helped provide an overview of the state of the art of the product category at hand and identify niche opportunities.

Iterative

The iterative nature of the approach and the use of different levels of prototyping techniques facilitated continued improvement, so the results were better (graphically and structurally), and the final package solutions had better integration of graphics and structure.

Divergent/Convergent Thinking

The alternating nature of the process and the use of Design Thinking tools increased both the number of opportunities, ideas, and the in-depth exploration of these ideas.

Management and Facilitation

By guiding teams through a series of well-designed steps with clear milestones, the bad praxis of leaving work for the end was eradicated. Face-to-face weekly meetings were vital to the success of the approach. They kept the team's focus and worked as a tool for effective decision making.

For the students, the experience represented an awakening call where they saw first-hand their immense creative potential. Besides learning fundamental problem-solving skills, students enriched their portfolio with quasi-professional pieces. These portfolio pieces are seen by students and potential employers as excellent talking points during interviews to land an internship or a first job. There is a learning curve to working in projects with people with diverse backgrounds. The experience prepares students for collaborative industry jobs by improving their communication skills. Student winners were provided the opportunity to gain money prizes, professional acknowledgment, and entrance into a career as a packaging professional.

For the academic programs, the experience improved the number of good projects and the overall quality of student work. The different cross-disciplinary interactions between graphic design and packaging students have taken learn-by-doing to a new level. Some competitions provide money prizes to programs; which help the programs build resources and offer a better learning experience to future generations. For faculty facilitating the experience, the collaborations kept the courses fresh and exciting. Even though the organization and implementation were challenging and time-consuming, the final result has been gratifying and inspirational.

The findings from this study also generated several questions for future research. The research suggests that a framework such as *Design Thinking Project-Based Learning* encourages creativity and overall quality of student's design work. On the other hand, it seems clear that the elements of this kind of approaches have associated costs (e.g., weekly face-to-face meetings, the involvement of multiple faculty members, small class groups) and it could become even more challenging with larger classes. However, actual economic research would need to be made to determine the opportunity cost for society resulting from low investment in design pedagogy [1]. Implementing pedagogical changes to include Design Thinking in actual courses is challenging. It requires of faculty members interested in and capable of teaching design in specialized fields. The question remains if technical and engineering schools would be willing to incorporate Design Thinking as part of the curriculum.

LIMITATIONS

The authors envisioned this research as a holistic approach to teaching design innovation and are aware that many variables have not been controlled. It is left to future research to understand better which elements of the DTPBL approach had a more significant impact on the success. Nevertheless, the work presented in this paper contributes to a better understanding of the implementation of Design Thinking methodologies in engineering education.

REFERENCES

- [1] C. L. Dym, A. M. Agogino, E. Ozgur, D. D. Frey, and L. J. Leifer, "Engineering Design Thinking, Teaching, and Learning," *J. Eng. Educ.*, vol. 94, no. 1, pp. 103–120, 2005.
- [2] L. W. (Ed) Anderson *et al.*, *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's taxonomy of Educational Objectives*, First Ed. New York City, USA: Longman, 2001.
- [3] A. Malhotra, J. C. Thomas, J. M. Carroll, and L. A. Miller, "Cognitive Processes in Design," *Int. J. Man. Mach. Stud.*, vol. 12, pp. 119–140, 1980.
- [4] H. A. Simon, "Problem Forming, Problem Finding, and Problem Solving in Design," in *Design and Systems: General Applications of Methodology*, A. Collen and W. W. Gasparski, Eds. New Brunswick, NJ, USA: Transaction Publishers, 1995, pp. 245–257.
- [5] L. B. Archer, "Whatever Became of Design Methodology?," *Design Studies*, vol. 1, no. 1, pp. 17–18, 1979.
- [6] K. Dorst and N. Cross, "Creativity in the Design Process: Co-Evolution of Problem-Solution," *Des. Stud.*, vol. 22, no. 5, pp. 425–437, 2001.
- [7] R. Buchanan, "Wicked Problems in Design Thinking," *Des. Issues*, vol. 8, no. 2, pp. 5–21, 1992.
- [8] H. Christiaans, "Creativity in Design: The role of Domain Knowledge in Designing," Delf University of Technology, 1992.
- [9] N. Bonnardel and E. Marmèche, "Evocation Processes by Novice and Expert Designers: Towards Stimulating Analogical Thinking," *Creat. Innov. Manag.*, vol. 13, no. 3, pp. 176–186, 2004.
- [10] N. Cross, "Expertise in Design: An Overview," *Des. Stud.*, vol. 25, no. 5, pp. 427–441, 2004.
- [11] D. Durling, N. Cross, and J. Johnson, "Personality and Learning Preferences of Students in Design and Design-Related Disciplines," in *Proceedings of IDATER 1996*, 1996, pp. 1–7.
- [12] D. Rams, "Ten Principles for Good Design," 2018. [Online]. Available: www.vitsoe.com/us/about/good-design. [Accessed: 05-Aug-2018].
- [13] National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press, 2004.
- [14] A. Altman, C. L. Dym, R. Hurwitz, and J. W. Wesner, "The Key Ideas of MDW VIII: A Summary," *Int. J. Eng. Educ.*, vol. 28, no. 2, pp. 501–511, 2012.
- [15] L. Oehlberg, I. Leighton, A. Agogino, and B. Hartmann, "Teaching Human-Centered Design Innovation Across Engineering, Humanities and Social Sciences," *Int. J. Eng. Educ.*, vol. 28, no. 2, pp. 484–491, 2012.
- [16] C. B. Zoltowski, W. C. Oakes, and M. E. Cardella, "Students' Ways of Experiencing Human-Centered Design," *J. Eng. Educ.*, vol. 101, no. 1, pp. 28–59, 2012.
- [17] S. R. Daly, E. A. Mosyjowski, and C. M. Seifert, "Teaching Creativity in Engineering Courses," *J. Eng. Educ.*, vol. 103, no. 3, pp. 417–449, 2014.

- [18] I. Mohedas, S. R. Daly, and K. H. Sienko, "Design Ethnography in Capstone Design: Investigating Student Use and Perceptions," *Int. J. Eng. Educ.*, vol. 30, no. 4, pp. 888–900, 2014.
- [19] V. Taajamaa, M. Eskandari, B. Karanian, A. Airola, T. Pahikkala, and T. Salakoski, "O-CDIO: Emphasizing Design Thinking in CDIO Engineering Cycle," *Int. J. Eng. Educ.*, vol. 32, no. 3, pp. 1530–1539, 2016.
- [20] S. McKilligan, N. Fila, D. Rover, and M. Mina, "Design Thinking as a Catalyst for Changing Teaching and Learning Practices in Engineering," in *Proceedings of Frontiers in Education Conference, FIE*, 2017, vol. October, pp. 1–5.
- [21] D. Kilgore, C. J. Atman, A. Jocuns, and S. Kathryn, "From Research to Action in the Classroom: Encouraging Broad Thinking in Engineering Design with Significant Learning Experiences," *Int. J. Eng. Educ.*, vol. 34, no. 2, pp. 659–673, 2018.
- [22] P. Gordon, J. Kramer, A. M. Agogino, R. Dzombak, and S. Martin, "Building 21st Century Skills Through Development Engineering," *Int. J. Eng. Educ.*, vol. 34, no. 2, pp. 619–631, 2018.
- [23] D. I. Levine, A. M. Agogino, and M. A. Lesniewski, "Design Thinking in Development Engineering," in *Proceedings of the 2015 Harvey Mudd Design Workshop IX*, 2014, vol. 32, no. 3, pp. 1396–1406.
- [24] N. Genco, K. Hölttä-Otto, and C. C. Seepersad, "An Experimental Investigation of the Innovation Capabilities of Undergraduate Engineering Students," *J. Eng. Educ.*, vol. 101, no. 1, pp. 60–81, 2012.
- [25] A. Mabogunje, N. Sonalkar, and L. Leifer, "Design Thinking: A New Foundational Science for Engineering," *Int. J. Eng. Educ.*, vol. 3(B), no. 32, pp. 1540–1556, 2016.
- [26] D. Twede and L. Bix, "The Advent of University-Level Packaging Scholarship: The Time, the Place and the People," *J. Appl. Packag. Res.*, vol. 9, no. 3, pp. 34–59, 2017.
- [27] H. W. J. Rittel and M. M. Webber, "Dilemmas in a General Theory of Planning," *Policy Sci.*, vol. 4, pp. 155–169, 1973.
- [28] W. C. Churchman, "Wicked Problems," *Manage. Sci.*, vol. 4, no. 14, p. B-141-42, 1967.
- [29] L. Bix, J. de la Fuente, R. P. Sundar, and H. Lockhart, "Packaging Design and Development," in *The Wiley Encyclopedia of Packaging Technology*, 3rd ed., K. Lam, Ed. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2009, pp. 859–866.
- [30] T. Brown, "Design Thinking," *Harvard Business Review*, vol. June, pp. 84–92, 2008.
- [31] R. Cohen, "Design Thinking: A Unified Framework For Innovation," *Forbes*, 2014. [Online]. Available: <https://www.forbes.com/sites/reuencohen/2014/03/31/design-thinking-a-unified-framework-for-innovation/#43e215788c11>. [Accessed: 14-Apr-2018].
- [32] K. Tschimmel, "Design Thinking as an Effective Toolkit for Innovation," in *Proceedings of the XXIII ISPIM Conference: Action for Innovation: Innovating from Experience*, 2012, pp. 1–20.
- [33] R. Martin, *The Design of Business: Why Design Thinking Is the Next Competitive Advantage*. Boston, MA: Harvard Business Press, 2009.

- [34] H. Poincaré, *The Foundation of Science*. New York City, USA: Science Press., 1924.
- [35] G. Wallas, “The Stages of Control,” in *The Art of Thought*, London, United Kingdom: Jonathan Cape, 1926, pp. 79–107.
- [36] E. Sadler-Smith, “Wallas’ Four-Stage Model of the Creative Process: More Than Meets the Eye?,” *Creat. Res. J.*, vol. 27, no. 4, pp. 342–352, 2015.
- [37] H. A. Simon, “The Science of Design: Creating the Artificial,” in *The Sciences of the Artificial*, 3rd Ed., Cambridge, MA: MIT Press, 1996, pp. 111–167.
- [38] IDEO, *The Field Guide to Human-Centered Design*, First Ed. San Francisco, CA, USA, 2015.
- [39] Hasso Plattner Institute of Design at Stanford University., “A Virtual Crash Course in Design Thinking,” 2017. [Online]. Available: <https://dschool.stanford.edu/resources/a-virtual-crash-course-in-design-thinking>. [Accessed: 01-Aug-2018].
- [40] K. Thoring and R. M. Müller, “Understading the Creative Mechanisms of Design Thinking: An Evolutionary Approach,” in *Proceedings of DESIRE’ 11, The Second Conference on Creativity and Innovation in Design*, 2011, pp. 137–147.
- [41] Design Council, “The Design Process: What is the Double Diamond?,” 2018. [Online]. Available: www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond. [Accessed: 04-Aug-2018].
- [42] M. Stickdorn and J. Schneider, *This is Service Design Thinking: Basics, Tools, Cases*, First Ed. Amsterdam, The Netherlands: BIS Publishers, 2012.
- [43] K. Tschimmel, D. Loyens, J. Soares, and T. Oraviita, *D-Think Toolkit: Design Thinking Applied to Education and Training*. 2017.
- [44] M. Petre, “How Expert Engineering Teams Use Disciplines of Innovation,” *Des. Stud.*, vol. 25, no. 5, pp. 477–493, 2004.
- [45] Cal Poly, “Graphic Design Concentration (2017-2019 Catalog).” [Online]. Available: <http://catalog.calpoly.edu/collegesandprograms/collegeofliberalarts/artdesign/#undergraduatetext>. [Accessed: 29-Jul-2018].
- [46] Cal Poly, “Packaging Concentration (2017-2019 Catalog).” [Online]. Available: <http://www.catalog.calpoly.edu/collegesandprograms/orfaleacollegeofbusiness/bsindustrialtechnologypackaging/packagingconcentration/>. [Accessed: 29-Jul-2018].
- [47] J. de la Fuente, S. Gustafson, C. Twomey, and L. Bix, “An Affordance-Based Methodology for Package Design,” *Packag. Technol. Sci.*, vol. 28, no. 2, pp. 157–171, Feb. 2015.
- [48] J. Ferri-Reed, “Quality, Conflict, and Communication Across the Generations,” *J. Qual. Particip.*, vol. 35, no. 4, pp. 12–14, 2013.
- [49] A. Milton and P. Rodgers, “How to Do Quick-and-Dirty Prototyping,” in *Research Methods for Product Design*, London, United Kingdom: Laurence King Publishing Ltd, 2013, pp. 118–119.
- [50] M. R. Fellenz, “Toward Fairness in Assessing Student Groupwork: A Protocol for Peer Evaluation of Individual Contributions,” *J. Manag. Educ.*, vol. 30, no. 4, pp. 570–591, 2006.

- [51] H. H. C. M. Christiaans, “Creative as a Design Criterion,” *Creat. Res. J.*, vol. 14, no. 1, pp. 41–54, 2002.
- [52] Paperboard Packaging Alliance, “Student Design Challenge,” 2018. [Online]. Available: www.paperboardpackaging.org. [Accessed: 27-Jul-2018].
- [53] Institute of Packaging Professionals, “AmeriStar Student Package Awards Competition,” 2018. [Online]. Available: www.iopp.org/i4a/pages/index.cfm?pageid=1713. [Accessed: 27-Jul-2018].
- [54] World Packaging Organisation, “WorldStar Student International Packaging Design Student Competition,” 2018. [Online]. Available: www.worldpackaging.org/wpo/14/. [Accessed: 27-Jul-2018].
- [55] SAS Institute Inc., “JMP® Pro v14.0.0 for Mac.” SAS Institute Inc., Cary, North Carolina, USA, 2016.
- [56] Turkish Packaging Manufacturers Association (ASD), “WorldStar Student Awards (2006-2014),” 2018. [Online]. Available: www.ambalaj.org.tr/en/competitions-student-competitions-worldstar-student.html. [Accessed: 28-Jul-2018].
- [57] World Packaging Organisation (WPO), “WorldStar Student Awards (2011-2017),” 2018. [Online]. Available: www.manage.worldpackaging.org/i4a/pages/index.cfm?pageid=3347. [Accessed: 28-Jul-2018].